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CASCADE IMPACTOR CALIBRATION GUIDELINES

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CASCADE IMPACTOR CALIBRATION GUIDELINES

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by

Seymour Calvert, Charles Lake, and Richard Parker

A. P. T., Inc.
4901 Morena Boulevard, Suite 402
San Diego, California 92117

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Industrial Environmental Research Laboratory
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This report contains guidelines for routine calibration of cascade impactors. The basic calibration technique discussed in the report generating uniformly sized particles, testing individual stages, determining particle number concentrations by light scattering, and calculating efficiencies for given test parameters. Each component of the technique is discussed. The results of calibrations of three cascade impactors and comparisons with published studies are presented.

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1.0 INTRODUCTION

The following report has been prepared at the request of the Particulate Technology Branch of the Environmental Protection Agency (E.P.A.) Utilities and Industrial Power Division. The contents are intended for use as a guideline for experimental calibration of cascade impactors (C.I.) and for Air Pollution Technology (A.P.T.) internal purposes.

The calibration process is based on approximately 4 years of A.P.T. experience in connection with work for the E.P.A. and other clients. In our experience, we have used University of Washington Mark III, Andersen non-viable (not the in-stack model), and A.P.T. M-1 cascade impactors and have found that calibration of these devices is necessary for accurate sizing of particles in gas streams. Variation of hole diameter and shape due to production machinery, corrosive chemical action, and particle deposition can contribute to measurement inaccuracy when using impactors. There are also discrepancies among the published studies of inertial impaction devices. Many C.I. manufacturers have not thoroughly calibrated their instruments experimentally but use the experimental results of Ranz and Wong (1952) even though Mercer and Stafford (1969), and Stern, et al. (1962) report much different results. Consequently, substantial uncertainties exist in the prediction of C.I. performance from past studies and manufacturer's specifications.

The basic calibration technique used by A.P.T. includes: generating uniformly sized particles, testing individual stages, determining particle number concentrations by light scattering, and calculating efficiencies for given test parameters.

The scope of this report covers the experimental technique, results of calibrations of three C.I.s, and comparisons with published studies.

2.0 AEROSOL GENERATION

2.1 CALIBRATION SYSTEM

The calibration system (Figure 1) consists of an air-liquid atomizer, aerosol drier, charge neutralizer, particle counter, dilution air lines and appropriate metering and flow equipment. Further details on the components are included in succeeding sections.

2.2 PARTICLES

Monodisperse aerosols can be produced using suspensions of polystyrene latex (PSL) spheres available from Dow Chemical Corporation. Original suspensions as received are concentrated, 10% by weight, and can be obtained with diameters ranging from 0.087 to 2.0 microns (μm) with a standard deviation of less than 0.01 μm, and a particle density of 1.05 g/cm^3. Suspensions of PSL spheres larger than 2 μm are available, however the standard deviations are much larger and the suspensions are more polydisperse.

Particles of 0.5 μm to 2.0 μm diameter have provided a sufficient size range for calibration of the lower 4 stages of both U.W. Mark III and A.P.T. C.I.'s. This is also the size range of most importance in fine particle control device evaluation. Consequently, A.P.T. has been most concerned with calibrations in this size range.

Useful suspensions of PSL can be made by diluting small quantities of the original suspension with deionized water. Any settling that occurs over a period of days can be re-suspended by gentle agitation. The PSL is diluted to a concentration sufficient to minimize the occurrence of agglomerates. Dilutions of stock 10% solutions of PSL can be estimated from a paper by Raabe (1969), however the amount of dilution necessary actually depends on the specific device used for spraying the hydrosol. Generally,

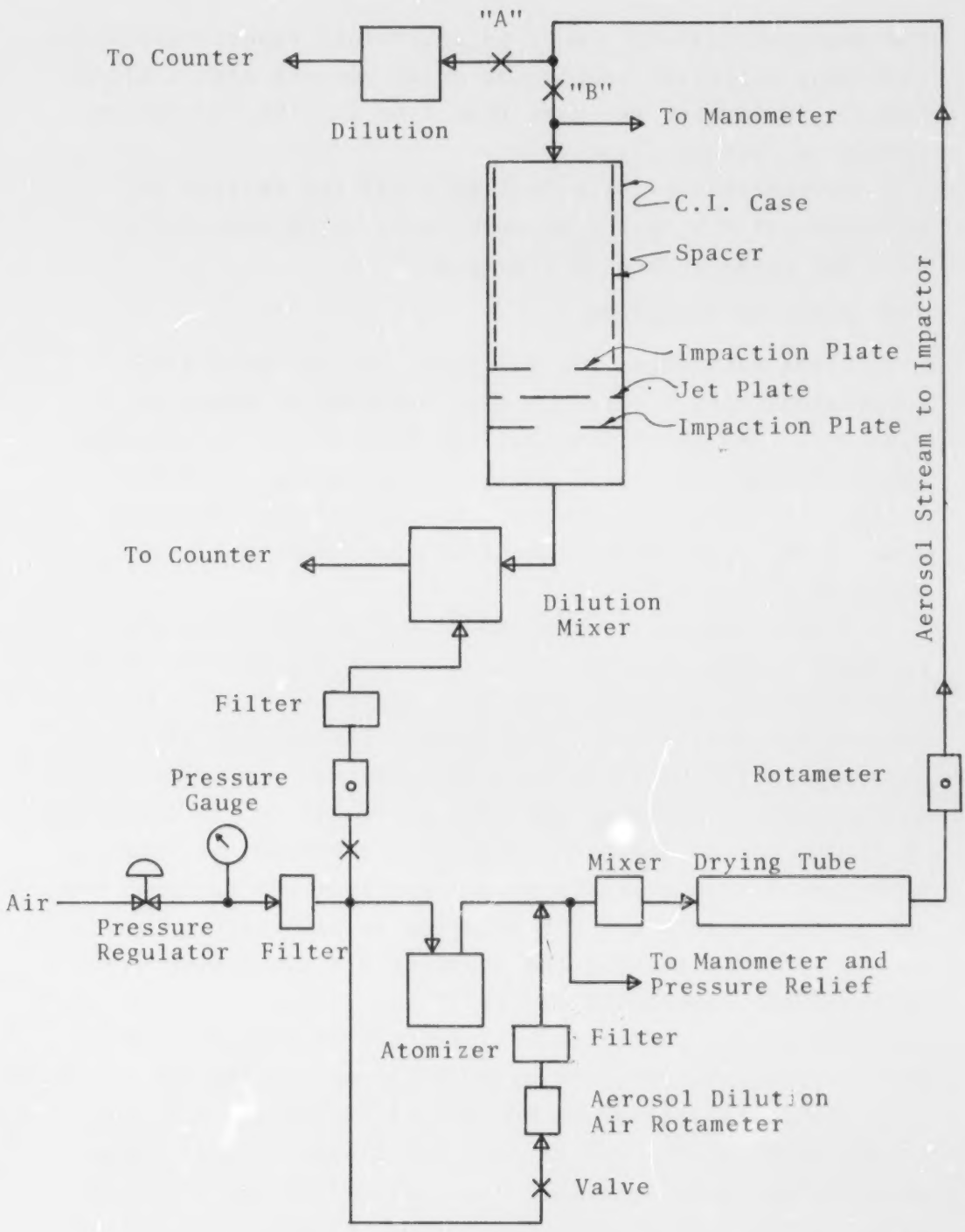

Figure 1. Calibration Apparatus

the necessary dilution must be determined experimentally by observing collected samples of dried aerosol with a microscope. If doubles run more than 2 to 5%, the suspension should be further diluted.

Concentrations of 0.004% to 0.03% (by weight) for particles of 0.5 to 2.0 μm were found to be compatible with the spray device in Figure 2.

2.3 PARTICLE GENERATOR

Drops containing PSL particles are produced from suspensions with a Collison type atomizer as shown in Figure 2. The operating range of this device is normally 170 to 350 kPa (10 to 50 psig) and operating characteristics vary with each device. May (1973) has tabulated some of the characteristics of a 3 jet model Collison atomizer (Table 1).

Number concentrations and drop size distributions produced by the atomizer are consistent for a given operating pressure, provided that the liquid level and concentration are maintained. Evaporation losses will cause an increase in the particle concentration and the number of agglomerates. This has not been a problem for test periods up to 3 hours in duration. For longer periods it would be necessary to periodically sample and test for agglomerates, and further dilute the PSL solution as necessary.

Drops leaving the atomizer are mixed with dry, filtered air (approximately 45 ℓ/min). This minimizes agglomeration of wet particles, dilutes the aerosol to a given number concentration, and aids in drying out the wet particles.

The aerosol is dried by passing it through a 1.2 m (4 ft) section of a 3.8 cm (1.5 in) diameter glass tube mounted horizontally with a layer of silica gel (~1.5 cm deep) spread evenly along the bottom. Three "Staticmaster

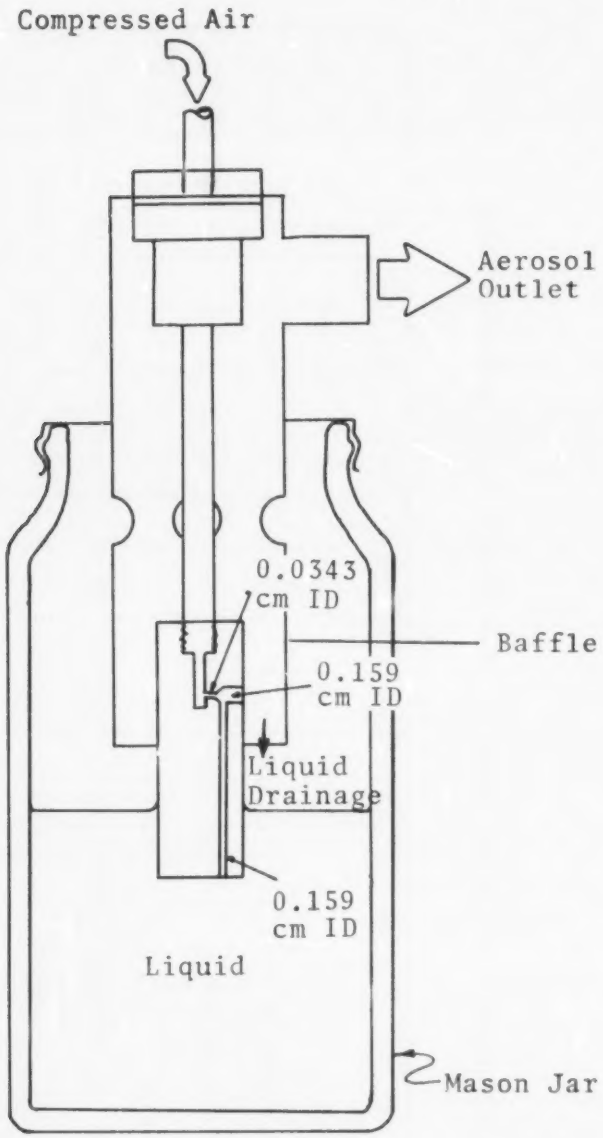

Figure 2. Collison Atomizer.

Table 1. OPERATING CHARACTERISTICS OF A 3 JET COLLISON ATOMIZER

Air pressure	kPa	103	138	172	207	276	345
Free air consumption	l/min	6·1	7·1	8·2	9·4	11·4	13·6
Water loss, drop + vapor	ml/hr	7·8	8·7	9·5	10·4	12·0	14·0
Approx. water vapor output	ml/hr	4·6	5·4	6·2	7·1	8·6	10·2
Approx. drop output	ml/hr	3·2	3·3	3·3	3·3	3·4	3·8
Total water conc. in outlet port	g/m^3	21·3	20·4	19·3	18·4	17·5	17·2
Droplet conc. in outlet port	g/m^3	8·7	7·7	6·7	5·9	5·0	4·7

2U500" 500 μc, Po^{210} alpha emitters (available from Nuclear Products Company) are situated end to end at the "dry" end of the glass tube to reduce the excess charge on particles to the minimum level described by Boltzman's law. No license is required to use these units.

3.0 PARTICLE CONCENTRATION MEASUREMENT

3.1 PARTICLE COUNTER

Particle number concentrations are determined using a Climet C1 205 Particle Analyzer. Other commercially available instruments utilizing similar "electro-optical" techniques are also satisfactory. The Climet device has the capability of counting all particles with diameters greater than a pre-set value (0.3, 0.5, 1, 3, 5, or 10 μm). Further discrimination can be achieved by using a potentiometer to provide a continuous selection over the range from 0.3 to 10 μm.

3.2 COUNTING PROCEDURE

The particle counter is used within a selected band of particle diameters, centered about the known PSL diameter. This reduces the effect of spurious counts resulting from fine impurities and agglomerates. The particle count for the larger diameter setting may be subtracted from that for the smaller diameter setting to determine the number concentration of particles within a desired size interval. It has been our experience that spurious counts may still be a problem within the size ranges available on the C1 205. Therefore, it is recommended that a potentiometer be used to zero in as closely as possible to the actual PSL particle size.

The maximum count allowed for the C1 205 is 3.5×10^7 /m^3 (10^6/ft^3). The sample must be taken from a stream at or very near ambient pressure. The C1 205 requires a flow rate of 7 ℓ/min.

The sampling inlet arrangement is illustrated in Figure 3. A 4 mm OD tube is used for the inlet to the particle counter. It is inserted a few millimeters into the sampling tube (10 to 15 mm ID). Thus a sampling flow

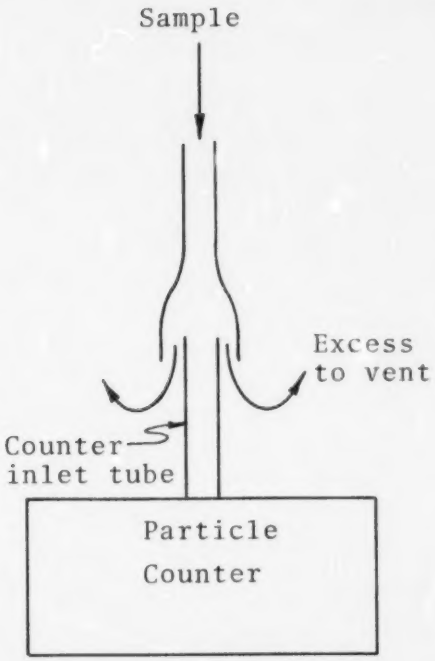

Figure 3. Sampling System Arrangement

rate larger than 7 ℓ/min is handled by letting the excess flow exit through the annular space between the tubes. This arrangement also ensures that the inlet flow to the particle counter is at atmospheric pressure. Tygon tubing and variable pinch clamps have been used satisfactorily as throttles to control the sampling flow rate and the flow rate through the impactor. They are shown as "A" and "B" in Figure 1.

4.0 CALIBRATION PROCEDURE

4.1 GENERAL CONSIDERATIONS

There are alternative approaches to calibration which offer advantages and disadvantages in terms of the amount of information gained versus the time, effort, convenience, and simplicity. Before going into the details of the calibration procedure, a few important principles will be pointed out.

Determining the stage cut diameter is the primary objective of the calibration. The computation of particle size distribution can be based on stage cut diameters with good accuracy, so long as particle bouncing on the upper (larger cut diameter) stages is prevented. Therefore, the calibration should concentrate on the particle size range in the vicinity of the stage cut diameter. For all stages, the inertial impaction parameter (defined in equation 1) at the stage cut point has a value of approximately 0.2. Therefore, it is suggested that the calibration of any stage should cover an impaction parameter range of 0.1 to 0.3. These values are for round jet impactors.

The present procedure calibrates one impaction stage at a time because it is simpler, in determining collection efficiencies from inlet and outlet particle concentrations, not to have to account for the contributions of two or more stages in series. Interference from the upstream plate, noted by Willeke and McFeters (1975), has been observed mainly for large particles in rectangular jets. Very little effect has been noted for small cut diameter stages with round jets. In calibrating single stages, however, it is necessary to ensure that the flow pattern is very nearly the same as in actual operation. Therefore, the present procedure requires an impingement plate to be placed upstream of the jet plate being calibrated. This arrangement is shown in Figure 1. Further experiments are

presently under way to determine the influence of one or more upstream impactor stages.

Some question has arisen as the expansion effects on hole diameter under hot and cold flow conditions. The most practical method for resolving this problem is to calibrate the impactor at various temperatures.

4.2 DEFINITIONS

The inertial impaction parameter is defined as follows

$$K_p = \frac{d_p^2\, C'\, \rho_p\, u}{9\, \mu_G\, d_c} = \frac{d_{pa}^2\, u}{9\, \mu_G\, d_c} \times 10^{-8} \qquad (1)$$

where K_p = inertial impaction parameter, dimensionless

C' = Cunningham slip correction factor =

$$1 + \frac{2\lambda}{d_p}\left|1.257 + 0.40 \exp\left(-1.10\, d_p/2\lambda\right)\right|$$

λ = mean free path of gas molecules, cm

d_{pa} = aerodynamic particle diameter, μmA

ρ_p = particle density, g/cm^3

u = gas (particle) velocity through jet, cm/sec

μ_G = gas viscosity, poise, g/cm-sec

d_c = jet diameter, cm

μmA ≡ μm $(g/cm^3)^{1/2}$

Aerodynamic diameter is defined as:

$$d_{pa} = d_p \left(C'\rho_p\right)^{1/2} 10^4, \text{ μmA} \qquad (2)$$

For the case where the stage is 50% efficient (i.e. the cut point), the following parameters are substituted into equation (1).

K_{p50} = inertial impaction cut parameter; K_p at 50% efficiency

d_{pc} = cut diameter or diameter (d_p) at which stage is 50% efficient

d_{pca} = aerodynamic cut diameter

Thus,

$$K_{p_{50}} = \frac{d_{pc}^2 \, C' \, \rho_p \, u}{9 \, \mu_G \, d_c} = \frac{d_{pca}^2 \, u}{9 \, \mu_G \, d_c} \times 10^{-8} \qquad (3)$$

4.3 PARTICLE SIZE SELECTION

.1 Obtain Theoretical Impactor Curves

Theoretical curves of cut diameter versus flow rate through the impactor are usually provided by the manufacturers of commercially available cascade impactors. These curves are generally based on some value of the inertial impaction parameter at the cut-point (i.e. $K_{p_{50}}$ in equation (3)). If these curves are not available, they may be approximated using equation (3) written in the form

$$d_{pca} = \left(\frac{0.135 \, \pi \, \mu_G \, d_c^3 \, N \, K_{p_{50}}}{Q \, (10^{-8})} \right)^{1/2} \qquad (4)$$

where Q = total flow rate, ℓ/min

N = number of jets or holes in an impaction stage

A good approximation may be obtained using $K_{p_{50}} \simeq 0.2$.

Curves of the aerodynamic cut diameter versus flow rate for the seven-stage A.P.T. M-1 cascade impactor are presented in Figure 4 and are based on $K_{p_{50}} = 0.2$.

.2 Determine PSL Particle Diameters and Flow Rates for the Calibration

The PSL particle diameters available commercially are listed in Table 2. The standard deviation is very large for particles greater than about 2 μm. Therefore, 2 μm is the largest size PSL particle suitable for use as a standard aerosol for calibration.

Table 2. AVAILABLE PSL PARTICLE DIAMETERS
(Source: Dow Chemical Company)

Avg. Diam. In Microns	One Std. Dev. In Microns	Material	Density g/ml
.087	.0046	Styrene-Butadiene	=1.05 unless otherwise noted
.091	.0058	Polystyrene	
.109	.0027	Polystyrene	
.176	.0023	Polystyrene	
.234	.0026	Polystyrene	
.255	.0022	Styrene-Butadiene	
.312	.0022	Polystyrene	
.357	.0056	Polystyrene	
.364	.0024	Styrene-Butadiene	
.460	.0048	Polystyrene	
.481	.0018	Polystyrene	
.500	.0027	Polystyrene	
.527	.0125	Styrene-Butadiene	0.99
.600	.0030	Polystyrene	
.721	.0057	Polystyrene	
.760	.0046	Polystyrene	
.794	.0044	Polystyrene	
.801	.0035	Polystyrene	
.804	.0048	Polystyrene	
.807	.0056	Polystyrene	
.822	.0043	Polystyrene	
1.011	.0054	Polystyrene	
1.099	.0059	Polystyrene	
1.101	.0055	Polystyrene	
2.020	.0135	Polyvinyltoluene	1.027
5.7	1.5	Styrene Divinylbenzene	
15.8	5.8	Polystyrene	

The aerodynamic diameter corresponding to a 2.02 μm diameter PSL particle can be calculated from equation (2) and is equal to 2.13 μmA. From Figure 4, it can be seen that for an aerodynamic cut diameter of 2.13 μmA, a minimum flow rate of 20 ℓ/min is required for Stage 4. Therefore, 20 ℓ/min is a convenient flow rate to use. From Figure 4 it can be seen that a flow rate of 20 ℓ/min corresponds to aerodynamic cut diameters of about 1.1, 0.6, and 0.4 μmA, for Stages 5, 6, and 7 respectively. The most suitable PSL particle diameters for each stage can be obtained from Table 2. Figure 5 is a convenient plot (from Calvert et al. (1972)) for the conversion between aerodynamic and physical diameters.

For example, assume that 0.5 μm diameter PSL particles are being used to calibrate Stage 7 of the A.P.T. M-1 impactor. From Figure 5, the corresponding aerodynamic diameter for a particle density of 1.05 g/cm^3 is about 0.58 μmA. The flow rate required for a cut diameter of 0.58 μmA is obtained from Figure 4 and equals about 8.5 ℓ/min. This cut diameter is for $K_{p_{50}} = 0.2$. Using equation (2), the flow rates required for $K_{p_{50}} = 0.1$ and $K_{p_{50}} = 0.3$ can be calculated to be 4.3 ℓ/min and 12.7 ℓ/min respectively.

4.4 IMPACTOR PREPARATION

.1 Inspect and Clean Impaction Plates

Inspect the jet orifices with a microscope to ensure that they are clean and round. If necessary, clear the orifices with a wire. Clean the jet and impaction plates in an ultrasonic bath with a detergent solution. Rinse first with distilled water, then with acetone. Re-inspect the jet orifices and repeat cleaning if necessary. Some jets may be irregularly shaped because of poor manufacturing. Such jets may be calibrated as they are, or returned to the manufacturer.

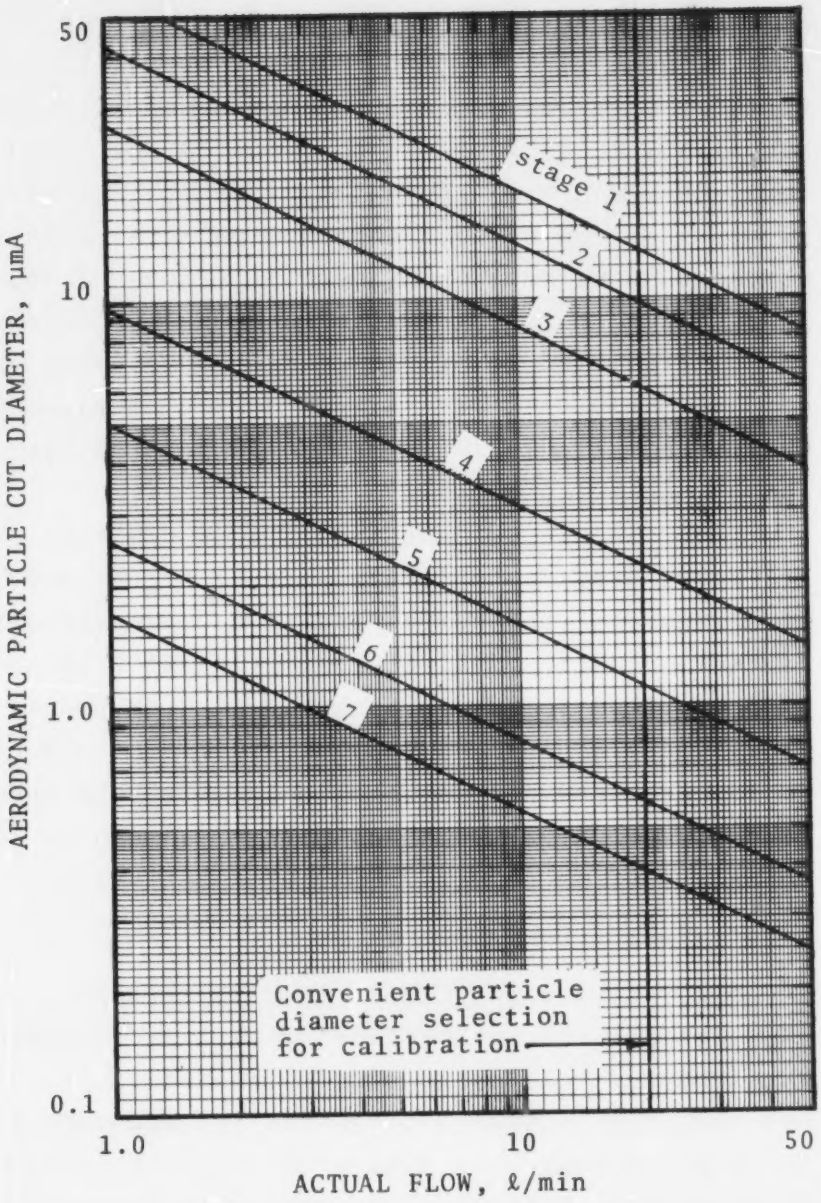

Figure 4. Aerodynamic cut diameter vs. impactor flow for A.P.T. M-1 cascade impactor.

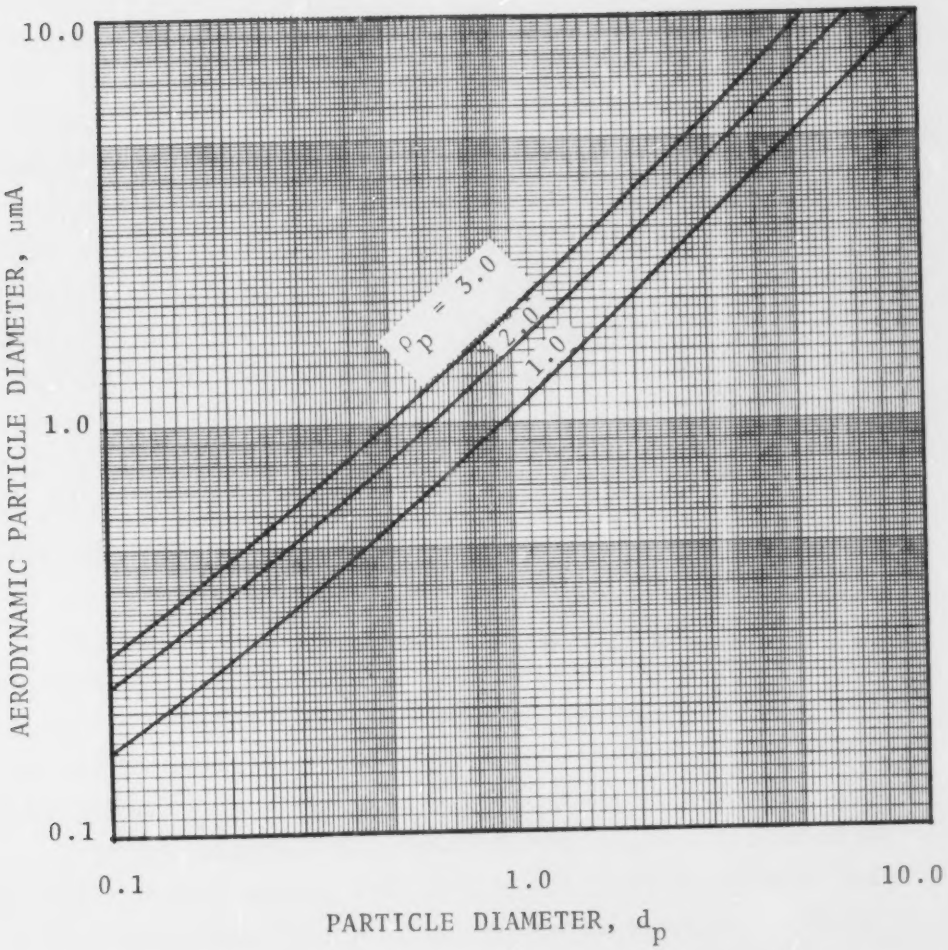

Figure 5. Aerodynamic diameter vs. diameter for various densities.

.2 Grease Impaction Plates

Apply grease to the impaction plates or foil substrates in the same manner as for normal laboratory or field use of the cascade impactor. A.P.T. uses Dow Corning high vacuum silicone grease or equivalent. If fibrous substrates are being evaluated, they should not be greased.

Because the particulate concentration will be counted upstream and downstream of the impaction plate, it is not necessary to perform a gravimetric analysis of the substrate and collected particulate. However, a gravimetric analysis is suggested as a check on the particulate mass balance of the system. If a mass balance check is being conducted, it is necessary to record the flow rate and time for the duration of the test. This will enable the prediction of the total particulate mass entering and leaving the system. The difference can then be compared to the mass collected on the impaction plate.

.3 Assemble Impaction Stage

Place the impaction stage in the calibration tube as shown in Figure 1. To provide the proper flow pattern, place an impaction plate upstream and downstream of the jet plate. The regular cascade impactor casing can be used as the calibration tube if tubular spacers are made to provide proper alignment and seals between the components. Alternatively a special calibration tube could be constructed.

4.5 MEASURE STAGE PRESSURE DROP

.1 Measure Pressure Drop as a Function of Flow Rate

This provides data which enable the use of the stage as an orifice flow meter during the calibration. It also provides a means for checking the jet orifice size by comparing the pressure drop flow rate data against data

for a known jet plate. This is a useful check both in the laboratory and in the field.

Measure the flow rate with a calibrated rotameter. The rotameter should be calibrated against a wet test meter every six months or whenever it is in disagreement with secondary flow measurements (for example the pressure drop measurements).

Measure the pressure drop across the impaction stage with an open end manometer attached to the upstream side of the impactor casing and downstream of throttle valve "B" in Figure 1.

.2 Plot Pressure Drop Against Flow Rate

Pressure drop is conveniently plotted against flow rate on log-log paper to give a straight line relationship. A typical impaction plate will have a pressure drop directly proportional to the square of the flow rate. For example, Stage 5 of a U.W. M-III impactor has a flow resistance which follows the relationship

$$\Delta P \text{ (cm W.C.)} = 0.2\ (Q)^2 \qquad (5)$$

4.6 PARTICLE PENETRATION

.1 Select Dilution Air Flow Rate

Select the dilution air flow rate necessary to dry the aerosol and also to bring it to the desired particle concentration range for counting. The general flow rate range is given in section 2.0 above.

.2 Start Dilution Flow to the Dryer

After checking the system to be sure that valves are open and closed as required to allow the flow to pass through the impactor stage, start the dilution air flow to the aerosol dryer. Use the pressure regulator, throttle

valves, and rotameter to adjust the flow rate.

.3 Load and Start Atomizer

Load the atomizer with about 500 ml of PSL suspension diluted from roughly 0.5 ml of concentrated latex. Start the atomizer, controlling the flow rate by adjusting the pressure regulator and the pressure gage. The atomizer flow resistance should be checked periodically by passing air from a dry atomizer (no liquid present) through a flow meter to detect any nozzle plugging.

.4 Adjust Flow Rate

Adjust the upstream sampling throttle "A" so that the pressure drop across the impactor is proper for the desired impactor flow rate, "Q". Keep throttle "B" open as much as possible. Set the outlet dilution air flow rate to provide more than 7 ℓ/min total flow into the particle counter.

When flow or concentration changes are made, approximately five system volume change time intervals should elapse before any data are taken to allow steady state conditions to be reached. This can take several minutes for some low flow rate impactors (e.g. Brink impactors).

.5 Measure Particle Concentration

Warm up the circuits of the particle counter for several minutes as recommended by the manufacturer. Particle counting should be done on the potentiometer setting as close as possible to the PSL particle diameter. To check the extent of agglomeration, it is helpful to use the next highest channel also. In general, record counts in all three channels, below, above, and at the PSL diameter.

The data recorded should include the following:

a. Stage identification
b. Particle identification parameters
c. Particle suspension (as used) specifications

d. Barometric pressure
e. All rotameter readings
f. All pressure readings
g. Air temperature at impactor inlet
h. Particle counts on 2 or 3 channels for inlet and outlet of impactor.

Make counts over the complete range of air flow rate going both up and down. Plot the data obtained in the simplest meaningful form so they can be checked for consistency. Computation methods as discussed in Section 5.0 are used to obtain particle penetration. A plot of penetration versus impactor pressure drop requires the least computation and serves the purpose. Inspect the plot for scatter of data and compare with the anticipated curve. If it is unsatisfactory, make any worthwhile modifications and repeat the run.

At this point it is advisable to inspect the impaction plate by eye and with a microscope. A visual examination can show whether the plate is overloaded. Microscopic examination of light deposits enables the detection of spurious particles.

Continue taking and plotting data until satisfied that reproducible data have been obtained.

5.0 RESULTS

5.1 DATA REDUCTION

.1 Compute inlet and outlet particle concentrations by subtracting the concentration measured on the high diameter channel from that measured on the lower channel. For example, if counting 0.5 μm diameter particles, subtract the concentration counted on the 1.0 μm channel from that counted on the 0.3 μm channel (see sample calculation, section 8.4). The net concentration should be equal to the concentration measured at the potentiometer setting closest to the PSL diameter. If this is not the case, spurious counts may be a problem, and the concentration measured closest to the PSL diameter should be used. If possible, use the potentiometer to narrow the band around the PSL diameter until no spurious counts are detected.

.2 Adjust outlet concentrations to the same (undiluted) basis as the inlet concentration in cases where dilution of the outlet sample has been necessary.

.3 Compute particle penetration, Pt, as the ratio of outlet to inlet particle concentrations (undiluted basis). Particle collection efficiency in fractional form is (1-Pt), and in percentage it is 100 times the fractional efficiency.

.4 Obtain the impactor gas flow rate from the previously determined plot of pressure drop versus flow rate, using the measured pressure drop for each penetration data pair.

.5 Compute inertial impaction parameter from the measured air flow rate and properties, particle properties, jet hole size and number of holes by means of equation (1). Jet velocity may be computed from the hole diameter, number of holes, and air flow rate.

.6 Results can be plotted in several ways, depending on their desired use. For checking the data quickly during the calibration procedure, a plot of penetration versus

impactor pressure drop is convenient. A plot of efficiency versus impaction parameter is more useful for interpretative purposes.

5.2 TYPICAL DATA

.1 Particle collection efficiency data points for a single calibration run on Stage 7 from an A.P.T. M-1 impactor are plotted against impaction parameter in Figure 6. The curve in Figure 6 represents the composite of data points for several Stage 7 runs.

.2 Data for four separate U.W. M-III Stage 5 plates are plotted in Figure 7.

.3 Figures 8 through 10 show the results of calibrations of the A.P.T. M-1, U.W. M-III, and Andersen non-viable cascade impactors in terms of collection efficiency versus impaction parameter for each stage. The curves represent the composites of several runs on different plates. Data points are omitted for clarity.

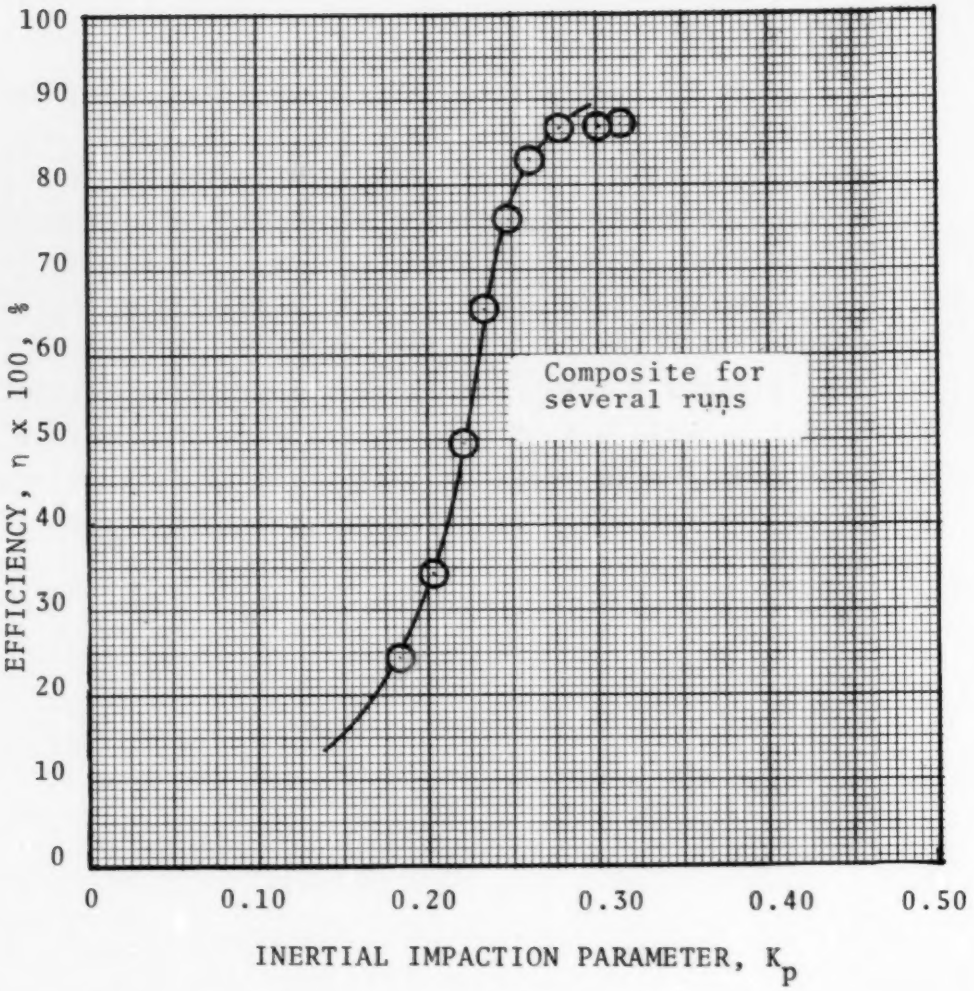

Figure 6. Efficiency vs. inertial impaction parameter for A.P.T. M-1 cascade impactor, stage 7

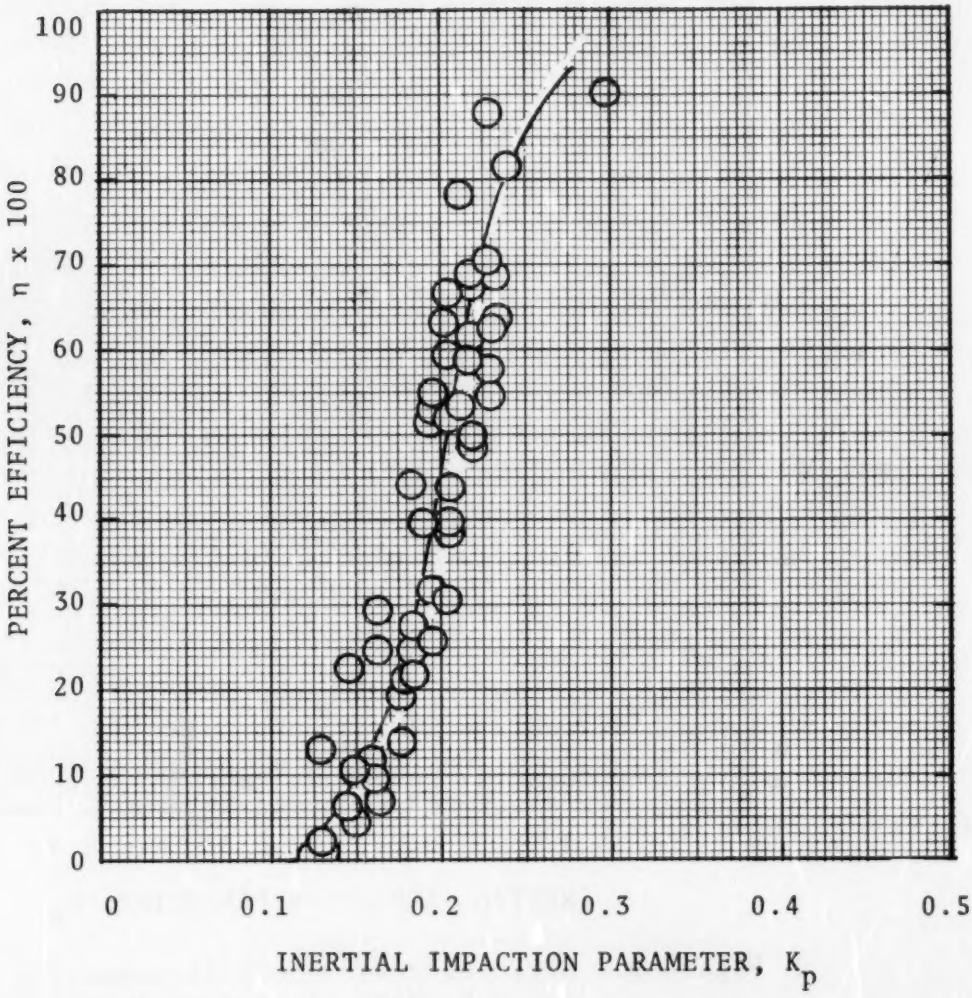

Figure 7. Efficiency vs. inertial impaction parameter, data from 4 separate U.W. Mark III cascade impactors (stage 5).

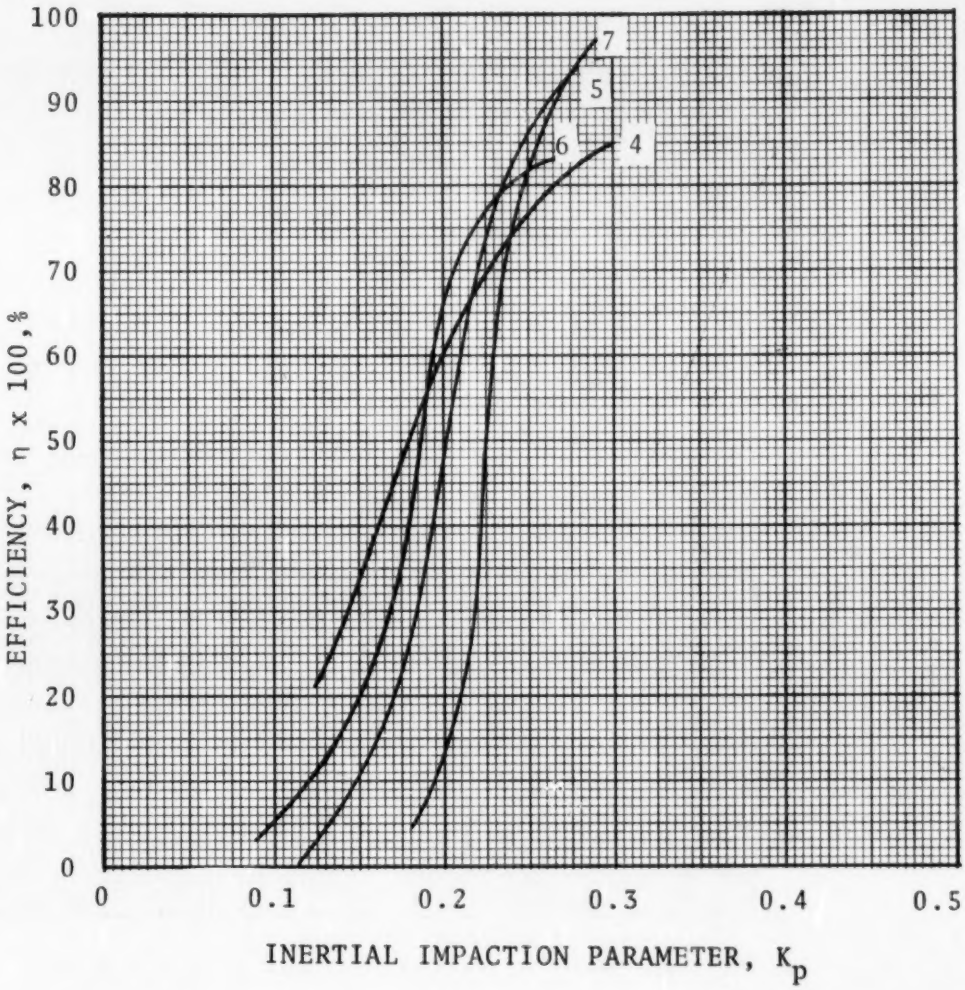

Figure 8. Efficiency vs. inertial impaction parameter for U.W. Mark IIIcascade impactor, stages 4-7.

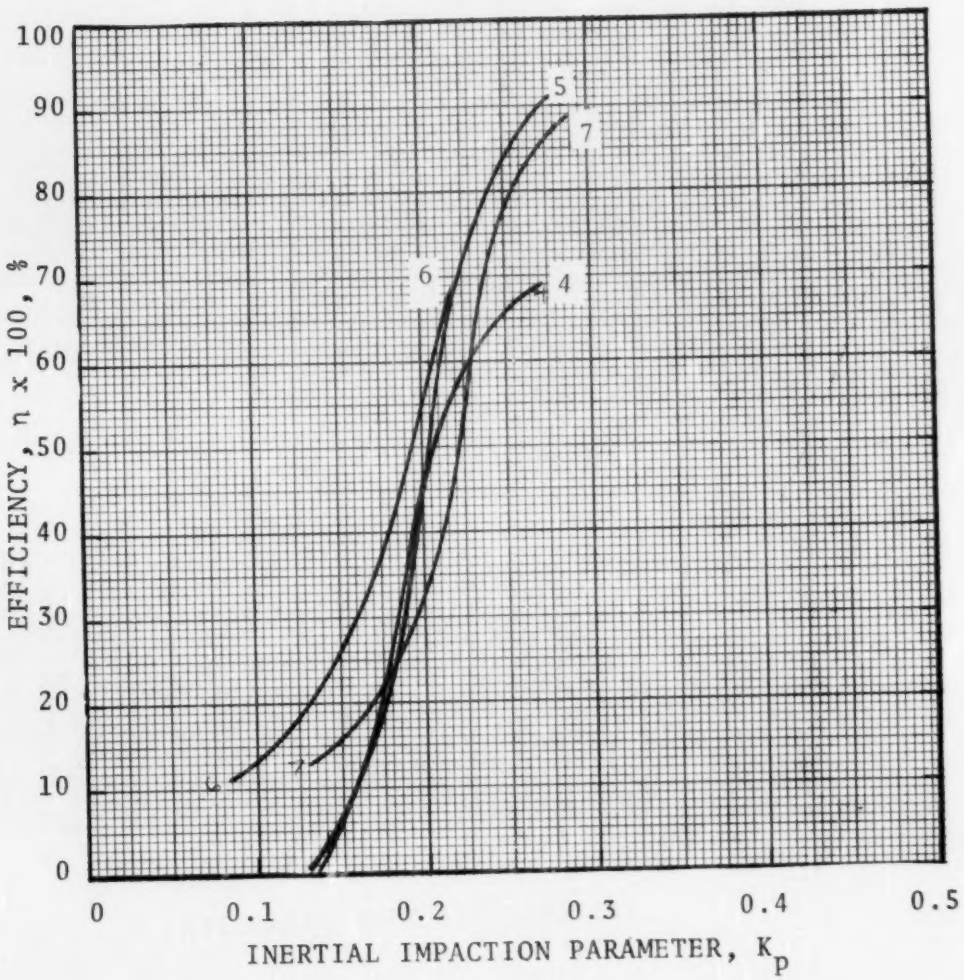

Figure 9. Efficiency vs. inertial impaction parameter for A.P.T. M-1 cascade impactor, stages 4-7.

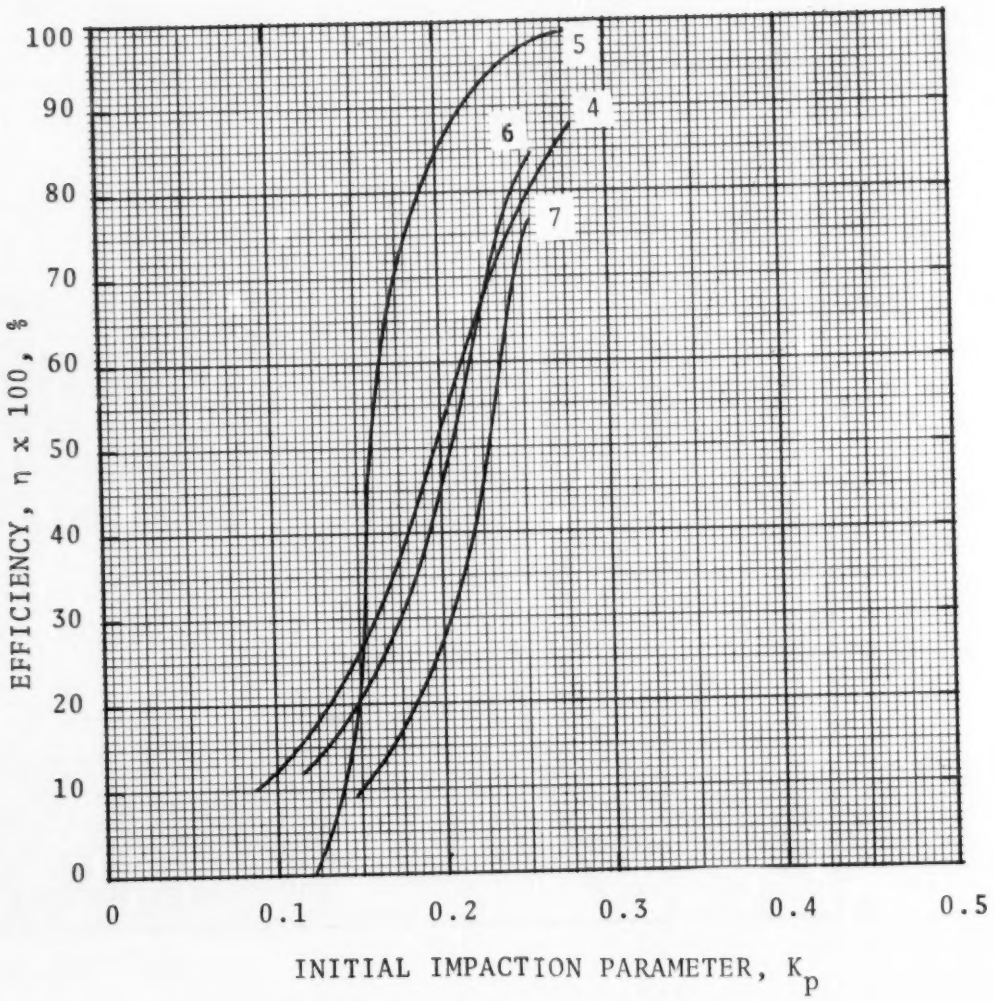

Figure 10. Efficiency vs. inertial impaction parameter for Andersen non-viable cascade impactor, stages 4-7.

6.0 DISCUSSION

6.1 REPRODUCIBILITY

The data obtained with the procedure described above have been quite reproducible, as illustrated by Figure 6. Generally the data for a single stage fall within a band width of inertial impactor parameter values ranging about 0.02 or 0.03. Thus, the scatter about a cut parameter is about ±8%. The corresponding scatter of cut diameter values would be ±4%. Similarly, a variation of ±10% in impaction parameter corresponds to a variation of about ±5% in particle cut diameter.

6.2 ACCURACY

One way to estimate the accuracy of the impactor calibration is to compare the results with published theory and experimental data. Figure 11 is an efficiency plot which compares the averaged results for all four stages of each impactor with a few published experimental and theoretical results. It can be seen that the overall average cut parameters are within a spread of about 0.03 (signifying about 8% spread of cut diameters) for everything but the Ranz and Wong experimental data.

Curves "C" and "D" show the effect of jet length to diameter ratio, s/d_c, ranging from 3 for "C" to 10 for "D", from Mercer and Stafford's experimental data. The jet length/diameter ratios for the impactor stages whose calibrations are reported here are presented in Table 3. It can be seen that the ratios range between 2.4 and 12.5, with the A.P.T. M-1 having the smallest variation.

Another factor whose effect is related to that of (s/d_c) is the shape of the orifice in the jet plate. Of

the three impactors calibrated, only the A.P.T. M-1 has converging orifices in the jet plates. For the impactors with cylindrical orifices the jet diameter and velocity depend on jet plate thickness as well as (s/d_c). While detailed discussion of impactor design and theory is beyond the scope of this report, it is important to note that such factors do influence the performance of the impactor and should be recognized when comparing experimental and theoretical results.

6.3 STAGE VARIATIONS

Turning back to Figures 8, 9, and 10, it can be seen that the cut characteristics are generally "sharp" (i.e. efficiency rises steeply over a small impaction parameter range). However, the fourth stages for both the A.P.T. and the U.W. impactors show a pronounced decrease in curve slope above the cut point. This suggests that particle bounce may occur at higher velocities for these stages.

The variation of cut parameter values is least for the A.P.T. stages and greatest for the Andersen. This is believed to be due in part to the close control of (s/d_c) and the use of converging orifices in the A.P.T. M-1. It was also noted that some of the jet holes in the Andersen plates tested were not round, but roughly triangular. Such non-uniformity of the jet holes could be responsible for variations in cut parameter between impactor stages.

6.4 CONCLUSIONS

The procedure outlined in this report provides a simple technique by which inertial impaction devices may be calibrated. Such factors as loading, particle bounce, wall losses, electrostatic and condensation effects, which may occur during source testing, are evaluated by this technique

to some degree. The calibration method, therefore, provides a reliable, intrinsic efficiency and is applicable to laboratory and field data obtained by careful C.I. operation.

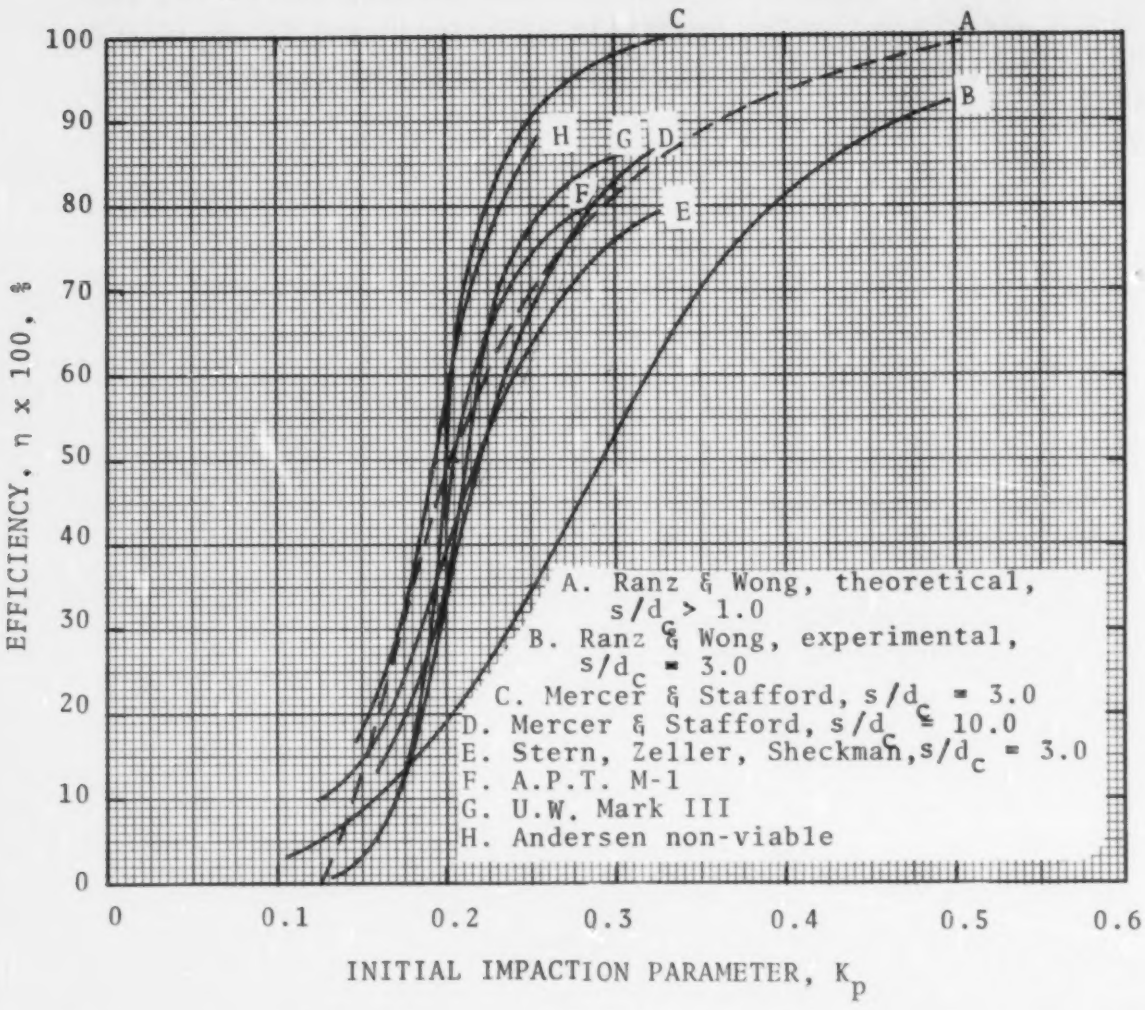

Figure 11. Efficiency vs. inertial impaction parameter for comparison.

TABLE 3: LENGTH/JET DIAMETER (s/d_c) FOR CASCADE IMPACTORS

Impactor	Stage - s/d_c			
	4	5	6	7
A.P.T. M-1	3.1	2.4	3.5	4.6
U.W.Mark III (New)	4.0	6.2	9.2	12.5
Andersen (Non-Viable)	4.7	7.3	9.8	9.8

7.0 REFERENCES

May, K.R. The Collison Nebulizer: Description, Performance and Application. Aerosol Science, Vol. 4. P. 235-243. 1973.

Calvert, S., Goldshmid, J., Leith, D., and Mehta, D. Scrubber Handbook. Environmental Protection Agency, Contract No. CPA-70-95. Vol. I. P. 4-148. 1972.

Ranz, W.E., Wong, J.B. Impaction of Dust and Smoke Particles. Industrial Engineering Chemistry. P.44, 1371. 1952.

Stern, S.C., Zeller, H.W., and Schekman, A.I. Collection Efficiency of Jet Impactors at Reduced Pressures. Industrial and Engineering Fundamentals. Vol. 1, No. 4. P. 273. 1962.

Mercer, T.T., Stafford, R.G. Impaction from Round Jets. Ann. Occupational Hygiene. Vol. 12. P. 41-48. 1969.

Willeke, K. and McFeters, J.J., The Influence of Flow Entry and Collecting Surface on the Impaction Efficiency of Inertial Impactors, J. Colloid and Interface Sci., 53, 121 (1975).

Raabe, O.G., Generation and Characterization of Aerosols, from Inhalation Carcinogenesis, Proc. of the Biology Division, Oak Ridge Nat. Laboratory Conf., Gatlinburg, Tennessee, October 8-11, 1969. (reference from personal communication from J. McCain, Southern Research Institute).

8.0 SAMPLE CALCULATIONS

8.1 AERODYNAMIC DIAMETER:

PSL Diameter - 0.5 μm
Particle density, $\rho_p = 1.05$ g/cm^3
Cunningham slip correction factor corresponding to a diameter of 0.5 μm, is 1.33

$$d_{pa} = d_p \left(C'\rho_p \right)^{1/2} = 0.5 \left((1.33)(1.05) \right)^{1/2} = 0.59 \text{ μmA}$$

(The use of Figure 4 yields a value of about 0.58 μmA)

8.2 GAS VELOCITY THROUGH JET:

Number of jets, N = 110
Diameter of jet, $d_c = 0.0343$ cm
Sample flow rate at conditions of operation,
Q = 20 ℓ/min

$$u = \frac{4Q}{N\pi d_c^2} = \frac{4(20)(1000)}{(110)(\pi)(0.0343)^2(60)} = 3.28 \times 10^3 \text{ cm/sec}$$

8.3 INERTIAL IMPACTION PARAMETER:

Gas velocity at conditions of jet, $u = 3.28 \times 10^3$ cm/sec
Viscosity of Gas at conditions of jet, $\mu_G = 1.8 \times 10^{-4}$ poise
Jet diameter, $d_c = 0.0343$ cm
Aerodynamic diameter = 0.58 μmA

$$K_p = \frac{d^2_{pa} u}{9\mu_G d_c} \times 10^{-8} = \frac{(0.58)^2 (3.28\times10^3)(10^{-8})}{9(1.8\times10^{-4})(0.0343)} = 0.20$$

8.4 CONCENTRATION MEASUREMENT

Consider PSL particle diameter = 0.5 μm

Impactor Inlet

Concentration on 1.0 μm channel = 0.01×10^6 cm^{-3}

Concentration on 0.3 μm channel = 1.01×10^6 cm^{-3}

Net concentration measured = $(1.01 - 0.01) \times 10^6$ cm^{-3}
= 1.00×10^6 cm^{-3}

Concentration at 0.5 μm potentiometer setting = 1.00×10^6 cm^{-3}

Sample flow rate before dilution = 3.5 ℓ/min

Sample flow rate after dilution = 7.0 ℓ/min

Actual concentration entering impactor,

$$n_i = \frac{7.0 \text{ ℓ/min}}{3.5 \text{ ℓ/min}} (1.00 \times 10^6 \text{ cm}^{-3}) = 2.00 \times 10^6 \text{ cm}^{-3}$$

Impactor Outlet

Concentration on 1.0 μm channel = 0.001×10^6 cm^{-3}

Concentration on 0.3 μm channel = 0.50×10^6 cm^{-3}

Net concentration measured = 0.50×10^6 cm^{-3}

Concentration at 0.5 μm potentiometer setting = 0.50×10^6 cm^{-3}

Sample flow rate before dilution = 3.5 ℓ/min

Sample flow rate after dilution = 7.0 ℓ/min

Actual concentration exiting impactor,

$$n_o = \frac{7.0 \text{ ℓ/min}}{3.5 \text{ ℓ/min}} (0.50 \times 10^6 \text{ cm}^{-3}) = 1.00 \times 10^6 \text{ cm}^{-3}$$

8.5 EFFICIENCY and PENETRATION:

Inlet concentration, $n_i = 2 \times 10^6$ particles/cm ^{3}
Outlet concentration, $n_o = 1 \times 10^6$ particles/cm ^{3}

$$Pt = \frac{n_o}{n_i} = \frac{1 \times 10^6}{2 \times 10^6} = 0.5, \text{ fraction}$$

$$\eta = 1 - Pt = 0.5$$

Percent efficiency = 0.5 x 100 = 50%

8.6 CUT DIAMETER FOR A GIVEN STAGE:

Inertial impaction parameter at 50% efficiency, $K_{p50} = 0.20$
Jet gas velocity, $u = 3.28 \times 10^3$ cm/sec
Viscosity of gas at conditions of jet, $\mu_G = 1.8 \times 10^{-4}$ poise
Jet diameter, $d_c = 0.0343$ cm

$$d_{pca} = \left(\frac{K_{p50} 9 \mu_G d_c}{u \times (10^{-6})} \right)^{1/2} = \left[\frac{(0.20)(9)(1.8 \times 10^{-4})(0.0343)}{(3.28 \times 10^3)(10^{-6})} \right]^{1/2}$$

$$= 0.58 \ \mu mA$$